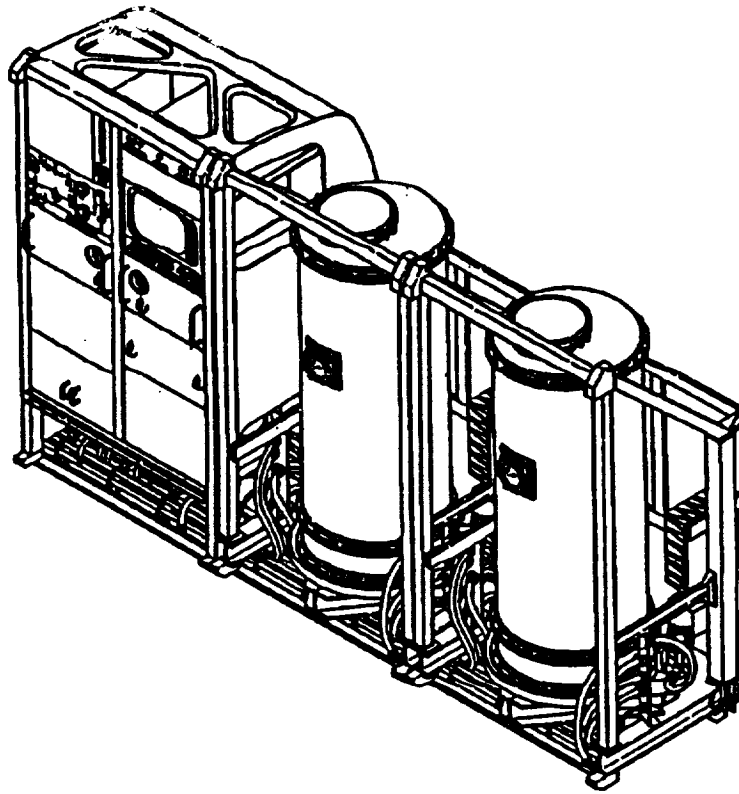


SPACE STATION FURNACE FACILITY

Executive Summary



DR-8
May 1992

Volume I
Final Study Report of
Space Station Furnace Facility
Contract No. NAS8-38077

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REQUIREMENTS DEFINITION AND
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SUMMARY (Teledyne Brown
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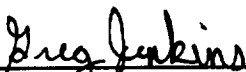
SPACE STATION FURNACE FACILITY

REQUIREMENTS DEFINITION AND CONCEPTUAL DESIGN STUDY EXECUTIVE SUMMARY


Contract No. NAS8-38077

DR-8

May 1992
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ABBREVIATIONS AND ACRONYMS

AADSF	Advanced Automated Directional Solidification Furnace
ATP	Authority to Proceed
CEI	Contract End Item
CGF	Crystal Growth Furnace
CoDR	Conceptual Design Review
COTR	Contracting Officer's Technical Representative
CRD	Capabilities Requirements Document
DMS	Data Management Subsystem
DR	Data Requirement
DTA	Demonstration Test Article
EMI	Electromagnetic Interface
FDDI	Fiber Distributed Data Interface
FDS	Fire Detection System
GCEL	Ground Control Experiment Laboratory
GDS	Gas Distribution System
GSE	Ground Support Equipment
HDRL	High Data Rate Line
Hz	Hertz
IRDU	Interrack Demonstration Unit
ISPR	International Standard Payload Rack
kW	Kilowatt
MSAD	Microgravity Science and Application Division
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NIU	Network Interface Unit
NTSC	National Television Standard Committee
ORU	Orbital Replacement Unit
PCDS	Power Control and Distribution Subsystem
PDR	Preliminary Design Review
PED	Payload Element Developer
PI	Principal Investigator
PMC	Permanently Manned Configuration
PMZF	Programmable Multi-Zone Furnace
PSA	Preliminary Safety Analysis

ABBREVIATIONS AND ACRONYMS (Conc.)

QD	Quick Disconnect
RDR	Requirements Definition Review
RPCM	Remote Power Control Module
SAG	Science Advisory Group
SCRD	Science and Capability Requirements Document
SOW	Statement of Work
SRW	Science Requirements Workshop
SSF	Space Station Freedom
SSFF	Space Station Freedom Facility
SSFP	Space Station Freedom Program
SSL	Space Station Laboratory
TBE	Teledyne Brown Engineering
TCS	Thermal Control Subsystem
USL	United States Laboratory
Vdc	Volts, Direct Current
3-D	Three Dimensional

INTRODUCTION

This Final Report was prepared by Teledyne Brown Engineering (TBE) in response to Data Requirement Number 8 (DR-8) of the Space Station Furnace Facility (SSFF) Requirements Definition and Conceptual Design Study Contract, NAS8-38077. The report consists of three volumes: Volume I, Executive Summary; Volume II, Technical Report; and Volume III, Program Cost Estimate.

The SSFF Project is divided into two phases: Phase 1, a Definition Study Phase, and Phase 2, a Design and Development Phase. TBE was awarded a research study entitled, "Space Station Furnace Facility Requirements Definition and Conceptual Design Study" on June 2, 1989. This report addresses the Definition Study Phase only. Phase 2 is to be completed after completion of Phase 1. This Phase 1 contractual effort included a basic contract of 12 months' duration with a follow-on option of 18 months. Effective with the award, Arthur S. Kirkindall, of the Marshall Space Flight Center (MSFC), was named Contracting Officer's Technical Representative (COTR) for this contract.

The contract encompassed a requirements definition study and culminated in hardware/facility conceptual designs and hardware demonstration development models to test these conceptual designs. The Study was divided into two parts. Part 1 (the basic part of the effort) encompassed preliminary requirements definition and assessment; conceptual design of the SSFF Core; fabrication of mockups; and preparation for the support of a Conceptual Design Review (CoDR). Part 2 (the optional part of the effort) included detailed definition of the engineering and design requirements, as derived from the science requirements; refinement of the conceptual design of the SSFF Core; fabrication and testing of the "breadboards" or development models; and preparation for and support of a Requirements Definition Review (RDR).

The CoDR was conducted on August 20 and 21, 1990, at MSFC, and Part 1 of the contract was completed on August 31, 1990. Approval for implementation of the contract Option (Part 2) was given on August 31, 1990. The CoDR Board's recommendations included several changes in the tasks planned for Part 2 of the contract. These recommended changes were incorporated into the contract with Modification 11, and Authority to Proceed (ATP) was given January 7, 1991. Part 2 culminated in an RDR which was held on May 12 and 13, 1992, at TBE. Part 2 of the contract was completed on May 31, 1992, with the submittal of the Final Study Report.

During this 36-month study effort, the TBE Study Team participated in three major Science Requirements Workshops (SRWs), six Quarterly Reviews, one CoDR, and one RDR.

EXECUTIVE SUMMARY

SPACE STATION FURNACE FACILITY REQUIREMENTS DEFINITION AND CONCEPTUAL DESIGN STUDY

BACKGROUND

The SSFF Study was awarded on June 2, 1989, to TBE to define an advanced facility for materials research in the microgravity environment of Space Station Freedom (SSF). The SSFF will be designed for research in the solidification of metals and alloys, the crystal growth of electronic and electro-optical materials, and research in glasses and ceramics. The SSFF is one of the first "facility" class payloads planned by the Microgravity Science and Applications Division (MSAD) of the Office of Space Science and Applications of NASA Headquarters. This facility is planned for early deployment during manned operations of the SSF with continuing operations through the Permanently Manned Configuration (PMC). The SSFF will be built around a general "Core" facility which provides common support functions not provided by SSF, common subsystems which are best centralized, and common subsystems which are best distributed with each experiment module. The intent of the facility approach is to reduce the overall cost associated with implementing and operating a variety of experiments. This is achieved by reducing the launch mass and simplifying the hardware development and qualification processes associated with each experiment. The Core will remain on orbit and will require only periodic maintenance and upgrading while new Furnace Modules, samples, and consumables are developed, qualified, and transported to the SSF.

The SSFF Study was divided into two phases: Phase 1, a Definition Study Phase, and Phase 2, a Design and Development Phase. This report addresses the Definition Phase 1 only. Phase 1 was divided into two parts: Part 1, the basic part of the effort, covered the preliminary definition and assessment of requirements; conceptual design of the SSFF; fabrication of mockups; and the preparation for and support of the Conceptual Design Review (CoDR). Part 2, the option part, covered requirements update and documentation; refinement of the selected conceptual design through additional trades and analyses; design, fabrication, and test of the Development Model; design, fabrication, and test of the Inter-rack Demonstration Unit; and support of the Requirements Definition Review (RDR). The purpose of Part 2 was to prove concept feasibility.

METHODOLOGY

The SSFF Study consisted primarily of two major activities: the development of the conceptual design and the demonstration of the concept feasibility using both the Development Model and Interrack Demonstration Unit. Also in the study were other SSFF activities undertaken in support of the Microgravity Science and Applications Division (MSAD) planning for payloads on the SSF. These included the following: MSAD user advocacy during the review of SSF capabilities and documentation; systems analysis and the generation of Space Station Furnace Facility (SSFF) interface requirements for mission planning activities; statusing the Science Community on SSF capabilities; and providing support in the implementation planning for SSFF development and operations.

The approach and methodology used for the SSFF conceptual design during the contract were as follows:

- Review the science requirements data in the Capabilities Requirements Document (CRD)
- Review existing furnace and furnace support system designs
- Review lessons learned from Development Models (Part 2 only)
- Develop conceptual designs
- Identify risk/cost driver requirements
- Present the impacts of risk/cost driver requirements at the Science Requirements Workshops (SRWs)
- Support followup technical interchange meetings with the Project Scientist and Furnace Developers
- Refine the concept based on any revisions to the CRD
- Prepare for each upcoming review.

This approach served two purposes during the conceptual design. First, it served to ensure that the facility design was responsive to the needs of the Science Community, and second, it served to identify cost drivers. As with all research payload developments, there must be a balance between the degree of fulfillment of science objectives and the associated impacts in terms of program risk and cost. The SSFF Study Team participation in the SRWs provided a forum to present the SSFF conceptual design to the Science Community and examine areas where the science requirements challenged or exceeded the current or projected state-of-the-art for a given capability. The SSFF Team prepared descriptions of concepts for implementing these capabilities; performed a wide range of specific trades resulting in alternate approaches; and prepared appropriate recommendations. Based

upon the material presented and subsequent splinter meetings, the CRD would be revised by the Project Scientist. Three SRWs were conducted to present technical data on the impacts of the critical requirements and present alternative approaches or capabilities that could be accommodated.

Part 1 culminated with a Conceptual Design Review (CoDR), convened at MSFC on August 20 and 21, 1990. The CoDR Board was appointed by the NASA Program Manager and consisted of a Science Panel and an Engineering Panel. The conceptual design presented was favorably accepted and was later updated to reflect changes (recommendations) from the CoDR Board to upscope the Statement of Work (SOW).

Part 2 followed the methodology used in Part 1, with the addition of a breadboarding process to assess and demonstrate the feasibility of the conceptual design. The conceptual design was analyzed to identify the critical features requiring demonstration. A Development Plan and a Demonstration Test Plan were developed to evaluate the critical features. After approval from the Contracting Officer's Technical Representative (COTR), these plans were implemented.

The Development Models were built utilizing commercial "off-the-shelf" equipment including flight-like cables and lines for physical simulation. The Development Model was demonstrated operating two different types of furnaces, representing a broad range of furnace operational characteristics. This test demonstrated the system's flexibility to operate advanced furnaces with diverse operational characteristics as the needs of the Science Community evolve.

The Interrack Demonstration Unit was developed to physically simulate the SSF International Standard Payload Rack (ISPR) interface and the lower portions of the SSFF racks. This unit was used to demonstrate and test the feasibility of routing fluid lines and cable runs between the racks. This system demonstrated a technically feasible approach to have common functions in one rack and route resources to adjacent racks.

In addition, facility packaging and the configuration layout was assessed through the development of a high fidelity mockup. Structures and components were fabricated to simulate the components in the flight unit conceptual design. Issues including component access, connector locations, cable routing, and component sizing were addressed. The unit was incorporated onto the Interrack Demonstration Unit to form a complete three-dimensional (3-D) representation of the SSFF.

The design and construction of the Development Model were modified as the Core conceptual design matured. Likewise, the Development Model design and construction influenced the Core conceptual design by yielding information and data relevant to

performance capabilities; design tradeoffs; requirements definition and refinement; and the verification of feasibility.

Throughout the contract, support actions were accommodated by performing a systems engineering analysis of the SSFF conceptual design at the time of the action and comparing the SSFF interface and resource requirements to the capabilities and provisions of the SSF. Shortfalls and impacts were identified and assessed as required.

SELECTED FACILITY CONFIGURATION

The SSFF Study culminated in the successful demonstrations of the Development Model and Interrack Demonstration Unit thereby proving the concept feasible. The SSFF Concept is illustrated in Figure 1. The SSFF will occupy three SSF International Standard Payload Rack (ISPR) locations in the United States Laboratory Module (USL) of the Space Station Freedom (SSF). Initial launch is scheduled for 1997, and continuing operations will extend beyond the year 2000. The SSFF is composed of the Core rack and two racks containing Furnace Modules. The Core rack provides the general and common subsystems required for the Furnace Modules, such as power conditioning, heat rejection, and data storage and communications, while the Furnace Modules provide the materials processing platforms and the experiment-peculiar subsystems. The Core consists of centralized components and subsystems housed in the Core rack, and distributed components and subsystems housed in the experiment racks. Under normal operations the SSFF Core rack will stay on orbit, and Furnace Modules will be changed out at 1 to 4 year intervals. The SSFF Core rack is a modular configuration, so that all of the components can be readily changed out on orbit for repair, maintenance, and upgrades. This modularity provides the essential flexibility to support the accommodation of advanced furnaces.

SSFF Core Subsystems

The SSFF Core System consists of five subsystems that interface with the SSF resources and convert or augment these resources to meet the requirements of the candidate SSFF furnaces. The subsystems are as follows: the Data Management Subsystem (DMS); the Gas Distribution Subsystem (GDS); the Power Control and Distribution Subsystem (PCDS); the Thermal Control Subsystem (TCS); and the rack replacement structures with mounting hardware for the rack packaging.

The SSFF DMS interfaces with the SSF DMS for status monitoring, access to SSF ancillary data, data downlink, and data uplink. It performs the functions of command and control for the SSFF Core subsystems and distributed signal conditioning and control for furnace operations. The DMS also provides for data storage and video processing.

The GDS provides Furnace Module access to the SSF Vacuum Vent System and gaseous nitrogen supply. The GDS also provides a supply of inert gas, such as argon, for backfilling the Furnace Module and contamination monitoring of the vent gases.

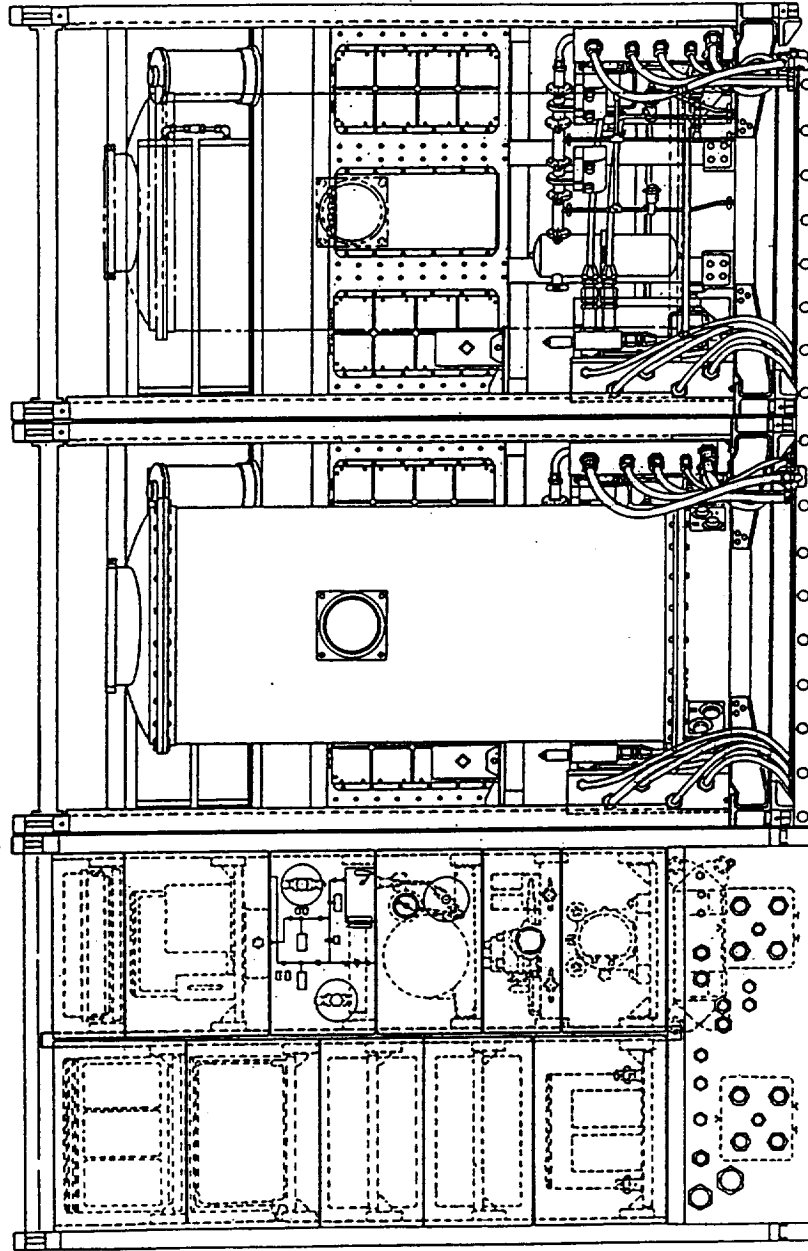


FIGURE 1: SSFF CONCEPT

The PCDS conditions the 120-Vdc power of the SSF to the variable power levels required by the furnace heater elements and auxiliary power levels required for translation motors, etc., and provides the necessary power distribution.

The TCS provides a secondary cooling loop to isolate the Furnace Modules from the SSF TCS cooling fluid. The TCS distributes the cooling fluid to each component requiring thermal heat rejection.

The rack replacement structures and mounting hardware provide the structure for transporting the Core to the SSF and housing the facility. The facility will occupy three ISPR locations.

The capabilities of the SSFF and more details on each subsystem are available in the Summary of Technical Reports, included in Part 6 of Volume II of the Final Report. The Preliminary Contract End Item (CEI) Specification is included in Part 1 of Volume II of the Final Report.

SIGNIFICANT ACTIVITIES AND ACCOMPLISHMENTS

The 36-month period of performance of this SSFF Study was punctuated by significant accomplishments, most of which were associated with the many activities relating to the main thrust of the contract — development of a feasible concept and proof of that concept through successful demonstration tests of the Development Model, Interrack Demonstration Unit, and mockups. The Development Model was a complete success. The Core facility controlled the two experiment modules independently and simultaneously. The system was demonstrated using load modules at first, which were subsequently substituted with two "live" furnaces. An Advanced Automated Directional Solidification Furnace (AADSf) prototype provided by NASA's Space Science Laboratory and a TBE developed Transparent Furnace were operated during the Development Model demonstration test.

During the interrack demonstration test, an interrack connection concept was demonstrated. The concept development objective was to provide for interfacing systems and components in three adjacent racks without impeding the ability to rotate any rack and without passing interconnections through the SSF standoff area. This system was developed using flight-like cables, conduits, and fluid lines. Fluid lines were charged and the vacuum lines were evacuated to represent on-orbit conditions. Tests were conducted demonstrating rack rotation without disconnecting any of the lines. This demonstrated that services such as a cooling water circulation could be maintained to a Furnace Module while the rack was rotated out for crew access. This interrack connection concept may have application to all future payloads and SSF subsystems which must be housed in multiple rack locations.

Other hardware developed under the Study include two facility mockups. The first was developed for the SSF mockup in building 4755 at Marshall Space Flight Center (MSFC) during the basic part of the contract. This mockup included a live display and control simulation and was demonstrated to Vice President Dan Quayle during his visit to MSFC. The second mockup was developed for installation on top of the Interrack Unit during Part 2 of the contract. This mockup was used as an engineering development tool to demonstrate the feasibility of the Orbital Replacement Unit (ORU) concept, to assess packaging density, and to assess the accessibility of many of the ORUs in the SSFF Core design. The development of this mockup led to changes in the configuration of selected ORUs, each of which was incorporated into the Core conceptual design.

In addition to the main thrust, the study process enabled the team to play a major role as an SSF User Advocacy Group by providing the opportunity for participation in the

SSF design reviews and providing technical justification for payload resource requirements. In this role the SSFF Study Team reviewed the SSF documentation and monitored changes in SSF capabilities to identify areas where the SSFF accommodation might be impacted. A direct product of this role was the development of realistic venting requirements data, compiled by taking gas samples from the Crystal Growth Furnace (CGF) and AADSF Ground Control Experiment Laboratories (GCELs), and developing a database of the types and amounts of materials vented from these furnaces.

It is worthy of note that because the SSFF is one of the first SSF payloads and requires a significant portion of the resources available on the SSF, it serves as a pathfinder for all other MSAD payloads.

SUMMARY OF RESULTS

The methodology used to develop the conceptual design was based on an iterative process involving three major reviews with the Science Community, six Quarterly Reviews, a Conceptual Design Review (CoDR) and a Requirements Definition Review (RDR). The CoDR and RDR Board consisted of NASA-appointed members sitting on either a Science Panel or an Engineering Panel. Additionally, the team attended Space Station Freedom (SSF) reviews to stay abreast of SSF changes and interfaces. Major updates and refinements were incorporated into the design after the SSF Preliminary Design Review (PDR), each Science Requirements Workshop (SRW), and the CoDR. Ongoing revisions to the conceptual design were incorporated as lessons were learned during the hardware development activities.

The SSF PDR resulted in the release of significant SSF interface detail and capability data, and the Core conceptual design was updated to reflect the various interfaces identified at this review. Also, subsequent restructuring of the SSF led to several interface trade studies, resulting in further design updates. The result of this evolution is an SSFF conceptual design that is compatible with the SSF interfaces for thermal cooling, vacuum, gaseous nitrogen, and power, and can be timelined or scheduled to operate with the resources available. The SSFF interfaces with the SSF Data Management System (DMS) through the Network Interface Unit (NIU) option for providing an interface with the Fiber Distributed Data Interface (FDDI) network for health and status monitoring, as well as for the uplink and the downlink of control and performance data. A High Data Rate Line (HDRL) interface will be required for downlink of high resolution video data. Standard National Televisions Standard Committee (NTSC) video will be transmitted through the analog video interface in the International Standard Payload Rack (ISPR). The SSFF concept is based on the premise that the Space Station Freedom Program (SSFP) will provide the following accepted and approved components for interfacing to the SSF systems: 8-kW water/water heat exchangers and Remote Power Control Modules (RPCMs); a Fire Detection and Suppression System (FDS); an NIU card; and an I/F card to the HDRL. The SSFF will be housed in three payload-developed and -controlled rack replacement structures and will be delivered as fully integrated racks to the SSFP.

PART 1

The initial phase of the contract consisted of two central activities: definition of the SSFF conceptual design and development of an SSFF mockup for the SSF mockup at

Marshall Space Flight Center (MSFC). The mockup was developed based on the initial concept for the SSFF Core. The system contained an active computer which ran a simulated control algorithm and displayed furnace control data. This mockup remains a key point of interest in the SSF mockup.

The conceptual definition of the SSFF required significant interaction with the Science Community to establish a thorough understanding of the science requirements. The Study effort supported three SRWs that were organized by Dr. Sandor Lehoczky of MSFC, the Project Scientist. These workshops were attended by members of the Science Community currently involved in research in solidification sciences including the current Principal Investigators (PIs) for the Crystal Growth Furnace (CGF) and the Advanced Automated Directional Solidification Furnace (AADSF). These participants formed the basis for the Science Advisory Group (SAG). These workshops provided updates to the Capability Requirements Document (CRD), JA55-032, dated August 11, 1988, which was the science basis for the initiation of the study effort. This document was updated for the second SRW and then revised after the third SRW.

The SSFF Study Team supported each of these workshops by preparing a presentation on the SSFF concept as it existed at the time of the workshop. These presentations emphasized the science requirements that challenged the state-of-the-art in technology; demanded resources that could not be provided in the SSF; required system configurations that were considered to be extremely hazardous; and/or greatly increased the system complexity, size, or mass. These science requirements were identified as potential high risk/cost drivers. For each such requirement, a recommended capability that could be accommodated without imposing a major risk or cost impact on the SSFF was presented. These technical interchanges on the science requirements provided the engineering team with more insight into the basis for the requirement leading to considerations of alternate means of achieving the desired science that was implied in the science requirements. These interchanges also provided a mechanism for containing the overall cost of the SSFF. Additionally, they provided the Science Community with a mechanism for obtaining information on the capabilities and constraints of the SSF and SSFF. In the future this process could provide the opportunity for PIs to focus their research programs planned for the SSFF within an envelop that can be accommodated on the SSF.

The First SRW

The first SRW provided an opportunity for the Science Community to be introduced to the SSFF Project and vice versa. The meeting was held on September 11 and 12,

1989, 4 months after contract Authority to Proceed (ATP). At that time, the technical detail in the conceptual design was not mature enough to justify major revisions to the requirements in the CRD. Results of trade studies comparing different approaches to provide the capabilities for hot ampoule exchange, ampoule mounting, and translation mechanisms were presented to the Science Community, and were determined to be low priority and specific to the unique design of each Furnace Module. These capabilities required tradeoffs between other science capabilities. For example, the capability for hot ampoule exchange must weigh the benefits of extracting the sample at higher temperatures versus the potentially detrimental impacts on previously processed samples. Approaches to insulate samples impact the volume available for samples in number and/or size. These trades are peculiar to each sample and mission set of samples, and they will require PI involvement. Because PIs had not been selected, direction was given to minimize the effort on these trades.

Quarterly Reviews

Throughout the Study, Quarterly Reviews were held for coordination of technical data, review of progress, and discussion of technical issues and task priorities. These reviews were chaired by the Contracting Officers' Technical Representative (COTR) and supported by the Chief Engineer and Project Scientist accompanied by their respective support personnel. The first Quarterly Review was held in September 21, 1989, shortly after the first SRW. This meeting focused on the recommendations and comments made by the Science Community. Objectives were set for the conceptual design, and direction was given to minimize the effort on trades and design activities pertaining to the Furnace Module.

The second Quarterly Review was held on December 14, 1989, to status progress on the effort. The conceptual design critical issues and ongoing trade studies were presented. The third Quarterly Review on April 17, 1990, was scheduled as a preview of the presentation to the second SRW. Cost driving science requirements were high-lighted and specific recommendations were discussed. After obtaining approval from the COTR, these presentations were updated and formalized for the second SRW.

The Second SRW

The second SRW was held on May 21 and 22, 1991. Critical risk and cost driver requirements were identified as those associated with large bore furnaces which could not

be accommodated in the volume of an SSF rack. Impact assessments on the Large Bore Bridgman and High Pressure Furnace, as defined in the CRD, were presented to the SRW. A large segment of this SRW was dedicated to presenting the SSF capabilities from the SSF PDR. In general, the SSF resource allocations for all users were not sufficient to satisfy the SSFF power, data uplink, data downlink, data storage, and vacuum vent level requirements based on the CRD requirements. In addition, impacts associated with furnace orientation/alignment and magnetic damping requirements were presented to the Science Community. These requirements were removed from the SSFF Core because these capabilities require a tradeoff in another science capability. As in the first SRW, trades impacting the science were deferred to the Furnace Module. These capabilities must be addressed during the Phase C/D effort by the Furnace Module Developer after PIs are selected. PIs must be involved in the determination of priority between ampoule-residual g-vector alignment and ampoule length (furnace size), and magnetic field strength and sample diameter. Contract Modification Number 4 directed the deletion of the High Pressure Furnace and Large Bore Bridgman from the list of candidates for accommodation by the SSFF Core, and it included a revised CRD based upon the results of the SRW. Recommendations to relax the acceleration measurement requirements and vacuum requirements were left unresolved, and the requirements for furnace orientation and magnetic damping were not removed from the the CRD.

The CoDR

The CoDR was held August 20 and 21, 1990, at MSFC. The design presented at the CoDR was based on the requirements in the CRD at the time of the second SRW. The SSFF Study Team delivered a draft Preliminary Project Implementation Plan, Function and Performance Specification Document, Summary of Technical Reports, Preliminary Safety Analysis, and the CoDR Presentation Materials. The Function and Performance Specification was a draft input for the Contract End Item (CEI) Specification. The Summary of Technical Reports contained the conceptual design reports for each of the subsystems in the SSFF Core, concepts for each Furnace Module in the contract Statement of Work (SOW), and trade study reports for each of the Trade Studies called for in paragraph 5.5 of the contract SOW. The Preliminary Safety Analysis (PSA) was performed in response to paragraph 5.10.6 in the contract SOW. The data in the PSA have been updated and incorporated into latest hazard report format identified for the SSFF. These reports are included in Part 3 of Volume II of the Final Report.

The CoDR Board

- Recommended the deletion of the Acceleration Monitoring System from the SSFF because this is a common requirement of all microgravity facilities, and it was determined that the cost and volume penalty should not be borne by each payload
- Recommended that the feasibility of interrack cables and lines be addressed in more detail
- Recommended the requirements for furnace alignment and magnetic damping be revisited by the Science Community
- Recommended that plans for in-flight reconfiguration be developed
- Recommended special attention be paid to hazardous material handling because of the stringent safety constraints imposed in developing the conceptual design and recommended that the system not be overdesigned for safety
- Expressed concerns over the size of the five rack configuration of the SSFF and availability of flight opportunities for such a large facility
- Questioned the approach of using furnace load modules to simulate a furnace and requested that "real" furnaces be incorporated in the Demonstration Test Plan

PART 2

After the CoDR, ATP with the Option was granted. The contract SOW was modified to incorporate tasks addressing the concerns and issues raised by the CoDR Board. These included the following: establishment of realistic venting requirements; incorporation of the CGF Demonstration Test Article (DTA) as a "real" furnace for the Development Model; development of the Interrack Demonstration Unit to test the feasibility of routing cabling and fluid lines between adjacent racks; development of safety procedures for handling hazardous materials; development of a configuration and safety and functional verification plans; and a task to increase the SSFF representation of the MSAD user community in the development of SSF resource allocations and mission planning. The additional tasks were incorporated into the contract, and ATP was received on January 7, 1991. In August of 1991, Modification 16 eliminated the tasks of developing of safety procedures for hazardous material handling and configuration control, safety verification, and functional verification plans, because the SSFP had not established appropriate guidelines and requirements documentation to support these activities.

Development Model Results

The design, development, and demonstration of the SSFF Development Model was a part of the Part 2 contractual effort. This model was designed to demonstrate the

feasibility of the SSFF concept. It also models the functions and physical interfaces of the SSFF Core, the SSF services, and the Furnace Modules.

A CoDR was held in August 1990. The documentation package for this review contained a draft of the Development Model Development Plan, which detailed the development approach established at that time. The package also contained several reports describing the concepts and requirements for the SSFF Core and its subsystem parts. This package and the comments received from the CoDR Board members formed the basis for the development of the SSFF Core and the Development Model concept.

In general the CoDR Board's comments were favorable, the efforts were approved, and ATP to the next phase (Part 2) was granted. One significant comment from the CoDR Board was that the Development Model should minimize the use of equipment and operations and, to the extent possible, utilize actual or high fidelity hardware models. It was also determined that the Development Model should operate with an actual furnace to provide the most realistic demonstration of concept feasibility. The model concepts and design were therefore modified to meet these directions.

Part 2 began in January 1991. The purpose of this phase, as stated in the SSFF contract, was to cover the updating of requirements and documentation; to refine the conceptual design based on CoDR inputs; to prepare for and support the Requirements Definition Review (RDR); and to design, fabricate, and test a Development Model to demonstrate design feasibility.

Another significant event that occurred around January 1991 was the restructuring of the Space Station based on congressional direction to produce a less costly design. Results of the restructuring activities were published in various forms from March to May 1991. These details were incorporated into the design.

Development Model

A Development Model Development Plan was published that provided the planning for the design, construction, and test of the SSFF Development Model. It presented the planned concepts and approaches for the Development Model based on the CoDR concept, incorporating the changes imposed by the SSF restructuring, as of the beginning of June 1991. The document included the requirements definition and preliminary design of the Development Model and addressed the detailed design, construction, and test.

The results of the Development Model effort are summarized in the following paragraphs. They are presented in conjunction with the applicable SOW tasks to delineate the specific results.

Contract SOW Paragraph - 5.3 Development Models Design, Fabrication, Assembly and Test

"The contractor shall design, fabricate, assemble, and test a development model of the core facility to demonstrate the feasibility of the design concept selected. The development model shall be designed to provide high-fidelity physical and functional interfaces with the experiment modules and Space Station interfaces to the extent that they are defined. Commercial grade parts and equipment will be acceptable for control and data acquisition systems, thermal control and other support systems. The development model shall be designed so that it can be configured to operate each type of furnace for selected "strawman" experiments. Operation of all types of furnaces in parallel is not required; however, parallel operation of the Furnace Modules in the USL shall be considered and the core facility development model shall be used to demonstrate this capability. Demonstration tests shall be conducted to demonstrate operations in the man-tended and fully manned modes."

The following is a discussion of the results of activities in response to specific elements of the SOW paragraph:

1) "...demonstrate the feasibility of the design concept selected."

The Development Model provided a Core Facility model, two furnace models, and a model of the Space Station services. A block diagram of the configuration is shown in Figure 1.1-1. The design is based on the SSFF CoDR concept and the changes incorporated due to SSF restructuring. The Development Model design allows for flexibility in configuration including a base configuration incorporating two load modules, and subsequent configurations incorporating combinations of load modules and real furnaces. The base configuration Development Model is designed to provide common centralized and common distributed services to two Furnace Modules. These were chosen to be a CGF-type furnace model since there was sufficient data available to model it, and a Transparent-type furnace model, selected for the same reason. The Core design provided required services and allowed for reconfiguration for operation with the different load module/furnace combinations. During the design and construction, communication of information between the Development Model design team and the conceptual designers aided in the establishment of requirements and specifications for the flight SSFF. Performance testing of alternate approaches not only demonstrated feasibility, but also enabled definitive comparisons of these approaches to be made.

2) "...provide high-fidelity physical and functional interfaces with the experiment modules and Space Station interfaces to the extent that they are defined."

The Development Model design provided high fidelity physical and functional interfaces to the extent they were defined. The interface definitions specified in the ISPR interface document were used as the basis for the SSF interface designs for the Development Model. Power, thermal, gas, and vacuum interfaces were modeled accurately. Unfortunately, the data interface was not fully defined; therefore, a model that approximated the functionality was used. The model has subsequently proved to be accurate, and its performance was

established to be well within the SSF data interface performance capabilities defined at the time.

- 3) "...designed so that it can be configured to operate each type of furnace for selected 'strawman' experiments."

The Development Model was designed to be reconfigurable for several types of furnaces. Data in the CRD for several furnace types was reviewed for service requirements. Detailed data, however, were available only for CGF. Some data were available for the Programmable Multi-Zone Furnace (PMZF) and were used in the design. Additionally, data from an in-house research project, the Transparent Furnace, were used in the design. Analysis of these data indicated that a hardware design that provided services to the CGF and PMZF would accommodate other furnaces. The Development Model software was also designed to be capable of reconfiguration for operation of other furnace types. This design ability to be configured for different types of furnaces was amply demonstrated by operating models of the CGF and Transparent Furnaces as well as operation of an AADSF prototype, provided by NASA Space Science Laboratory (SSL) as Ground Support Equipment (GSE), and a Transparent Furnace developed and fabricated by TBE.

- 4) "...parallel operation of the Furnace Modules in the USL shall be considered and the core facility development model shall be used to demonstrate this capability"

Three Demonstration Tests met these objectives. Definition of these tests is documented in a Demonstration Test Plan published as part of the Final Report. Operation of the SSFF Development Model was formally demonstrated with three different load module/furnace combinations. The combinations were operated using typical operation timelines defined for the demonstration. The operational scenarios included functions designed to demonstrate operations aboard the SSF, including staggered timeline operation to meet power constraints. The three Demonstration Test configurations were (1) a CGF-type furnace load module and a Transparent-type furnace load module operated simultaneously, (2) a CGF-type furnace load module and the "real" SSL AADSF operated simultaneously, and (3) a "real" Transparent Furnace and a "real" SSL AADSF operated simultaneously.

- 5) "Demonstration tests shall be conducted to demonstrate operations in the man-tended and fully manned modes."

During development of Demonstration Test scenarios, it was established that operations in the fully manned mode were a subset of operations in the man-tended mode (intended for demonstrating automated processing operations). The test were, therefore, carried out in man-tended operations.

Interrack Demonstration Unit

This section presents a summary of the results from the Development Model effort to demonstrate the feasibility of interconnecting the multiple racks of the SSFF. The purpose of the work performed under this task was to develop a conceptual design for

interrack fluid and electrical connections in the SSFF; test the design; and demonstrate the feasibility of the concept. The effort included a concept design and trade study, construction of an Interrack Demonstration Unit (IRDU), and testing the performance of the IRDU.

The contract SOW paragraph covering this effort is as follows:

"The development model must demonstrate and prove the feasibility of the inter-rack connections dictated by the SSFF conceptual design. It may be necessary to build a separate demonstrator to prove the feasibility of the inter-rack connections."

After some initial analysis, a determination was made to build a separate model for the IRDU. Combining the two Development Models would have complicated both designs and compromised the performance in both models. The added packaging and interface fidelity would have resulted in additional cost. By separating the two models, the physical interconnect issues could be separated from the functional issues in the Development Model permitting the use of commercially available equipment.

The development of the IRDU started with an examination of the typical furnaces listed in the CRD and the SSFF conceptual design as a baseline. Initially the concept provided separate lines for services to each experiment, but that baseline would not fit in the space allowed. A reduced-connection complement of services was developed, satisfying the services requirements of the experiments, but sharing the interconnections. This interconnect concept was implemented in a demonstration unit.

Key issues in the concept design were (1) providing an adequate cable count for payload power and data lines and (2) creating a realizable and maintainable design. A key technical issue that drove the development of the physical model to prove the interconnect system functionality, was the requirement to maintain services without restricting the racks from being tilted out rapidly for access to the pressure hull. Previous interrack cabling designs, such as those used on the Spacelab, are fixed in place and do not permit on-orbit behind-rack access without time consuming cable and fluid line removal. SSFF is a critical application of tilt-out compatible interconnects due to the nature of furnaces. Most furnaces will contain sufficient energy during operation to represent a significant hazard if coolant flow were suddenly interrupted. The SSFF interrack connection architecture permits rack tilt-out without severing service connections to the experiment.

A Test Article was constructed to determine whether the proposed interconnect architecture could function within the confines of an SSF module installation. The test article was used to verify cable and hose routing, access to connectors, panel layout, and operating forces. It models the lower one-third of the Core facility and two experiment

racks. Only modeling of the lower portion of the racks was required because the upper portions were not affected by the interconnect design. SSF ISPR interface plate position and rack pivot points were precisely modelled. Counterbalances were installed on the Core rack and one experiment rack to eliminate the forces from the structure during the measurement of forces due to cable and hose flexure. These balance weights placed the center of gravity (CG) of the test article near the rack rotation axis when the racks were in the normal operational position. Cable and hose flexure cause a change in the CG location during tilt-out, so that the counterbalance becomes less effective as the racks are rotated out. Therefore the measured loads are considered conservative.

Torques were measured during testing. The highest torque recorded for either tested rack was less than 250 inch-pounds. This is equivalent to approximately a 5-pound force applied at a rack handle located 50 inches from the rotation axis. No human factors force limits were violated during any rack tilt-out operation. The conclusion from testing was that the rack interconnect design presented is suitable for use on the Space Station from a human factors standpoint.

All connectors were found to be accessible for service changeout, and cables and hoses could be removed from the system without difficulty. With the single exception of the vent hose, all interconnect components had acceptable bend radii at any rack position.

Test results showed that the design developed for SSFF interconnection systems is feasible and represents low development risk.

Quarterly Reviews

The fourth Quarterly Review was held on February 21, 1991, to discuss specific approaches for accomplishing the tasks incorporated into the contract with Modification Number 11. Particular emphasis was placed on the Development Model. The contract Study Plan and Development Model Plan were submitted and approved at this Quarterly Review.

The fifth Quarterly Review was held on June 28, 1991, to coordinate and review the presentation material for the third SRW, planned in July. This SRW was delayed until October because of the availability of key participants from the Science Community. No Quarterly Review was held during the fall of 1991 because the third SRW served as a forum to status the progress of the conceptual design.

The sixth Quarterly Review was held January 22, 1992, to coordinate with MSFC on preliminary findings and establish task priorities in preparing for the RDR. This review consisted of a presentation of the conceptual design status, open technical issues, and drafts

of the RDR documentation. An updated Study Plan was submitted and approved at this review. This was the last Quarterly Review.

The Third SRW

The third SRW was held on October 28 and 29, 1991, at MSFC. Risk/cost driver impacts on the requirements for vacuum venting, peltier pulsing, video data rates, onboard storage requirements, and power requirements were presented to the Science Community as part of the conceptual design presentation. All of the subject requirements were revised except the requirement for peltier pulsing. It was agreed that this requirement would be levied on the Module Developer and that the SSFF Core would be required only to provide the power and thermal interfaces to support its operation. The peltier pulsing device interfaces directly with the ampoule and provides a current flux across the sample, the characteristics of which are dependent on the sample material. Further, the power supplied to the ampoule is a function of the electrical properties of the sample, the cartridge material, and the sample geometry. In light of these interdependencies, it was deemed appropriate that the peltier pulsing function be a part of the Furnace Module development, which requires trades between the current requirements and cartridge material and will include PI involvement. It was recommended that peltier pulsing be levied as a requirement on the Furnace Module Developer, but no action was taken.

Requirements Definition Review

The revised CRD developed after the third SRW was used as a basis for update of the conceptual design. In addition, significant data were becoming available from the hardware development activities, integration testing, fabrication, and assembly. The conceptual design was revised to incorporate the latest requirements in the CRD and the data being obtained from the hardware development activities. The resulting concept was presented at the RDR and is the concept submitted in the Final Report. The SSFF Study Team delivered copies of the presentation materials which contained the following charts defining the SSFF conceptual design; the hardware capabilities of the SSFF and each subsystem; traceability to the particular science requirements in the CRD; identification of key issues which will drive the cost of the SSFF; and mission operational scenarios pertaining to mission sequencing on the SSF carrier. The Study Team also delivered the documentation identified in Table 1. These documents are included in Volume II of this Final Report. The Preliminary CEI Specification was delivered in April to the COTR and, after a subsequent

revision by NASA, was placed under configuration control. A copy of this latest version of the CEI Specification is included in Volume II of this Final Report.

TABLE 1 RDR DELIVERABLES

Preliminary Project Implementation Plan - Contains project schedules and descriptions of the activities associated with the development, launch, and operations of the SSFF.

Preliminary Experiments/Facilities Requirements Document - Contains the preliminary experiment requirements data for analytical integration.

Summary of Technical Reports - Contains detailed data on the concepts for the subsystems which comprise the SSFF Core.

ORU Assessment Report - Contains a summary of the trades and analyses performed to select the components as optimum candidates for on-orbit changeout.

Reprogramming Strategies Assessment Report - Contains a summary of the trade study between various options for reprogramming the SSFF for new experiments while on orbit.

Mission Operations - Contains a summary of the data compiled for furnace operational timelines.

TRADE STUDIES AND ANALYSES

During the Study contract, several trades and analyses were performed to support the SSFF Core conceptual design effort. Summary reports for each trade study, except the cost drivers trade studies and the Core common subsystems trades, are included in Volume II, Part 6, of the Final Report. Trade studies conducted during the Study included:

- Furnace Facility Breakpoints
- Impact of the Requirement for Furnace Orientation
- Hot Ampoule Exchange
- Ampoule Mounting
- Translation Mechanisms
- Impact of the Requirement for Magnetic Suppression
- Cost Driver Trades
- Core/Common Subsystems

Furnace Facility Breakpoints

The Furnace Facility Breakpoints trade study was performed during Part I of the study. This study served as the basis for establishing the modularity of the SSFF Concept. The initial approach to the study was to identify all of the functions required to operate the candidate solidification experiments and categorize them into those that are common to all experiments and those that are experiment specific. This determination was made based on the range of the function and the requirements for accuracy and control over the operational range. A narrative report discussing the division of these functions was provided at the CoDR, and the study also identified the need to address on-orbit reconfigurability of the SSFF Core in more detail. On-orbit reconfiguration and access requirements became major drivers of the conceptual design during Part 2.

Furnace Orientation

The impact of the requirement for furnace orientation was assessed prior to the second SRW. A review of the SSF configuration was performed, and magnitudes of the residual g-vector components were estimated and compiled for several locations in the SSF USL. Several concepts were developed for systems that could be used to place the furnace bore in alignment with the residual g-vector. The best location for the SSFF, where the magnitude and direction (with respect to the furnace bore) of the residual g-vector are minimized, is in the ceiling on the aft side. It should be noted that the optimum furnace

orientation is highly dependant on SSF configuration and torque equilibrium attitude. This study concluded that the furnace must be rotated out of the rack envelope to align with the residual g-vector, which would greatly complicate the Furnace Module cabling and the plumbing. Further, the CoDR Board expressed concern about the violation of the rack envelope and the protrusion into the aisle. To eliminate this protrusion the furnace envelope would have to be reduced. This would necessitate either a decrease in the sample length or the elimination of sample translation. This issue was identified as a trade that required an active participation of each specific PI, and the requirement to provide furnace orientation was shifted to the Furnace Module Developer. This completed the activity on this assessment.

Ampoules and Translation Mechanisms

Three trade studies are called for in the SOW pertaining to ampoules: Hot Ampoule Exchange, Ampoule Mounting, and Translation Mechanisms. TBE developed a summary report on Ampoule Exchange, Mounting, and Translation and associated presentation material for the first SRW and the CoDR. The report addressed the advantages and disadvantages of options for hot ampoule extraction, universal ampoule mounting devices, and common translation equipment. It was, however, determined that these trades were furnace dependent and that the design of the Furnace Modules was too immature to justify detailed trade study. The tasks were, therefore, discontinued, on direction from the first SRW, after only limited work had been done on the subjects.

Magnetic Suppression

Another assessment reviewed with the Science Community was an impact assessment of the requirement for magnetic suppression, or damping, of the residual convective flows in the melt. Three types of magnetic systems were considered in this study: superconducting magnets, permanent magnets, and electromagnets.

Superconducting magnets were eliminated because of their reliance on cryogenic cooling and the safety hazards associated with "quenching" phenomena. A quench is an unpredictable loss of superconductivity in the magnet. Basically the electrical resistance returns to part of the magnet winding, and the current generating the magnetic field is converted to heat due to I^2R losses. This heat then flashes the cryogenic fluid and large amounts of boiloff are created. The large vent gas amounts and consumable requirements, coupled with the risk of explosion, eliminated the superconducting magnet from consideration. Permanent magnets were considered, but they tend to be quite large for the 2000 gauss fields required and cannot be turned off easily. Permanent magnets must be shielded

during the on-orbit installation of the furnace and magnetic sample suppression system, as well as during the periodic sample harvesting between runs. This study identified the Spacelab limit for magnetic fields as 0.3 gauss at the surface of the payload. This field level is very restrictive, and magnetic shielding would be a major issue for all three types of magnetic systems. The current approach for shielding is to place a material that has a very low reluctance path around the magnet. Typically these materials, such as mu-metal, are very dense. For a 2000 gauss magnet, the shielding mass would be prohibitively high for furnaces of significant size. Techniques for shielding, using counter magnets to cancel out the field, were considered. Unfortunately, the addition of these secondary magnet systems increases the weight nearly as much as the shielding, and the stray magnetic field outside the secondary magnet would exceed the 0.3 gauss limit and still require passive shielding. Further, the use of a secondary magnet alters the desirable magnetic field generated by the primary magnet system and passing through the furnace sample. In general, the use of magnetic damping would require very heavy shielding that probably cannot be launched within the integrated configuration because of the launch load limits. For magnetic systems of significant size, the shielding would probably have to be assembled on orbit. Logistics activities associated with moving the magnet between the Shuttle and SSF and down the aisle of the laboratory will likely impact the operations of magnetic storage media and require the shielding to be in place. Electromagnets were considered and recommended as the best option for a Magnetic Suppression System. Electromagnets can readily be turned off during logistical resupply activities that require access to the furnace. In addition, these magnets offer the highest field strength for a given mass. The downside of these magnets is the power required for operation. The implementation of magnetic suppression will require a tradeoff between allocating power to the magnet or to the furnace heater modules. Consequently, the capability was deferred to the Furnace Module Developer.

After the second SRW, responsibility for the Magnetic Suppression System was transferred to the Furnace Module because the trades between magnet bore, field strength, sample diameter, furnace temperature, and shielding mass are specific to the Furnace Module design. This activity was completed and presented at the CDR.

Cost Drivers

A major emphasis has been placed on the study and assessment of cost drivers. At each Science Requirements Review, the major role played by the SSFF Study was to assess the technical feasibility and cost impact of providing the capabilities required in the CRD. In some cases the estimated cost impact was presented, but typically the driver would be addressed in terms of increased resource requirements, increased complexity,

increased risk, and safety hazards. All of these conditions tend to drive up the cost associated with developing and integrating a payload. Recommendations made to the Science Community included the following: raising the vacuum level requirement to $10\text{E}-3$ torr, from the $10\text{E}-5$ torr requirement currently baselined, to eliminate the need for vacuum pumps in the SSFF; reducing the overall facility power requirement to the 12 kW available on SSF; identifying video compression technology to reduce the video storage and transmission requirements; and limiting the furnace diameter to sizes that would fit in a standard rack volume, thereby eliminating the need for on-orbit assembly of large furnaces. Much like the Core/common subsystem trades, the cost driver trade activity was a continuous process of evaluating options in the design.

Core/Common Subsystems

The Contract SOW called for a trade on Core/common subsystems furnace unique systems. This trade was combined with the Furnace Facility Breakpoints trade study and reported at the CoDR during Part 1. The activity served as a continuous, iterative selection process for the SSFF Core conceptual design, resulting in selection of the common subsystems in the SSFF Core. In summary, all functions related to the interfacing, conditioning, and augmentation of SSF resources should be handled by the common subsystems in the Core. The SSFF Core subsystems are defined in the concept reports, and the assessments and trades are included in the Summary of Technical Reports.

RECOMMENDATIONS

Based on the results and findings of the study, the following recommendations are submitted.

Recommendation 1: that breadboards be developed and candidate cartridge materials tested early in the development program. The longer mission durations expected on the SSF will amplify the problems associated with materials compatibility between the cartridge materials and the Furnace Module materials. Data should be obtained for a wide range of candidate cartridge materials and compiled for the PIs as reference data in selecting the cartridge design.

Recommendation 2: that detailed trades be performed during the Phase C/D effort to address sample orientation and magnetic suppression for selected experiments. PIs should be selected early in the Furnace Module development, so that these trades can be done in time to permit implementation of selected approaches. PIs must be involved in the determination of priority between ampoule-residual g-vector alignment and ampoule length; ampoule diameter versus magnetic damping field strength; translation rate range versus translation accuracy; and all design detail associated with the manipulation and mounting of the ampoule. The impacts associated with the requirements for furnace orientation and magnetic suppression should be revisited as more mature data becomes available on the acceleration environment of the SSF. The magnetic suppression system should be deferred until after Permanently Manned Configuration (PMC), when possible advances in higher temperature superconductors might be incorporated in the system design. Furnace orientation should be considered for the early missions when additional room might be available before all of the SSF rack locations are utilized. This system should not, however, be incorporated into the first mission of the SSFF in order that experience may be gained in the installation of the system without the added complexity of the orientation system.

Recommendation 3: that the Furnace Modules for the SSFF be designed to contain all hazardous materials after an ampoule or cartridge failure. The centralized waste storage system should be maintained as an option in case the contamination monitoring system cannot be accommodated. Waste gas storage should be limited to only one purge cycle volume of gas for safing after nominal operations and before refurbishment. The waste gas storage involves a trade between storage volume and storage pressure. High pressure storage demands a large power consumption to drive multistage compressors. This

system will be very costly in terms of pump development cost and SSF resources, but should be considered as a means of safing the Furnace Module for return to Earth after a failure with a sample of hazardous material.

Recommendation 4: that the requirement for peltier pulsing be levied on each Furnace Module with the SSFF Core being required to provide the power and thermal interfaces to this device. The peltier pulsing device interfaces directly with the ampoule and provides a current through the sample. The current and power supplied to the ampoule is a function of the electrical properties of the sample and cartridge materials. The peltier pulsing function should be addressed under the Furnace Module development program to permit optimization of the current flux through the given sample and cartridge material for selected experiments for which this capability is a high priority.

Recommendation 5: that MSAD develop a standard payload rack that is maintained and integrated under the control of MSAD. This rack should be designed to replace an ISPR and to be integrated into the SSFP following the same procedures and protocols used during the delivery of payload racks by the International Partners. This procedure would be analogous to the methodology used on the Fluid Experiment System/Vapor Crystal Growth System on Spacelab for a preintegrated rack. The development of a standard payload rack will permit Payload Developers to adapt the rack to specific payload applications. The rack structure will be certified in conjunction with the payload structures at some additional cost to the development over using standard racks. This cost will, however, be more than off-set by reductions in the costs of performing electromagnetic interference (EMI), off-gassing, and fit test on the integrated system in the actual flight rack. In addition, system compatibility problems will be eliminated earlier in the program at the PED site, eliminating travel and premium labor cost after the payload has been delivered. For the SSFF, the requirements for interrack connections between the Furnace Modules and the SSFF Core, coupled with the size, height, and access requirements of the Furnace Module, dictate an alternative to the SSF standard rack.

Recommendation 6: that vent gas samples be taken from each flight furnace and Ground Control Experiment Laboratory (GCEL) during the final stages of development. For sample materials that cannot be vented, each Furnace Module should establish a method of detecting ampoule failures or provide containment such that a ruptured ampoule will not lead to the sample material entering the vent line. A trade study between ampoule failure detection and

additional furnace containment approaches should be performed during Phase C/D. Ampoule failure detection will be dependent upon the sample material and ampoule materials and cannot be addressed properly until a PI is selected.

Recommendation 7: that consideration be given to using the technology developed for quick disconnects (QDs) by the SSF for all fluid and water lines in the SSFF design. MSAD should monitor the progress of these design activities and distribute the technology to all Payload Developers. The SSFP must solve issues associated with these devices to enable completion of the SSF buildup and assembly on orbit. Nearly all SSF systems that require thermal cooling will require the mating and demating of fluid line connectors on orbit. Problems associated with air entrainment, leakage, and recharging must be addressed during the deployment of the SSF subsystems. MSAD Payload Developers should not be required to address this issue independently. Procedures and hardware used by the SSFP to solve these problems should be applied to MSAD facilities.

Recommendation 8: logistical resupply for the SSFF to accommodate refurbishing the furnaces on the ground every year, or every other year. Furnace heater elements and thermocouples are embedded in the Furnace Module and cannot be replaced on orbit. Problems associated with containment, on-orbit alignment and calibration, crew availability, and material interactions during high temperature processing add risk to the approach of refurbishing the Furnace Modules on orbit. Multiple flight Furnace Modules should be developed to support continuous operations.

Recommendation 9: that the initial Core configuration components be soft packaged in a logistical carrier that attenuates the loads imposed on each component. For example, packaging these components in foam and shipping them in stowage containers would reduce costs associated with structural design, analysis, and verification for launch loads. This should not impact the component performance on the SSF.

Recommendation 10: that Furnace Modules be scarred to provide attachments for accelerometer heads for measurement of local accelerations at vibroacoustic frequencies (> 10 Hz). These accelerometers should be developed by MSAD as a common item used by all SSF facilities. The data generated by these accelerometers should be stored by the SSFF when critical thresholds are crossed. These thresholds should be determined with the PI based upon a trade of acceleration data versus experiment processing data.